Simulation of Light Coupling Reciprocity for a Photonic Grating

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Introduction: SOI (Silicon on Insulator) technology utilizes silicon components on SiO_2 layer. Silicon waveguides carry signals on a SOI microchip. Propagating electric field distribution in a waveguide is called mode of the waveguide. Photonic gratings (Fig. 1) are formed by etching grooves on the top of a waveguide. Gratings can operate in two directions. They can guide incident beam into a waveguide or a waveguide mode out of the structure.

Aim of the study: We study the grating operation by utilizing optical reciprocity (1), which manifests that coupling of light between a waveguide and an optical fiber should not depend on the propagation direction. This principle allows for study of operation in two directions and determination of the coupled and lost power. Acquired knowledge can be used to optimize the grating geometry.

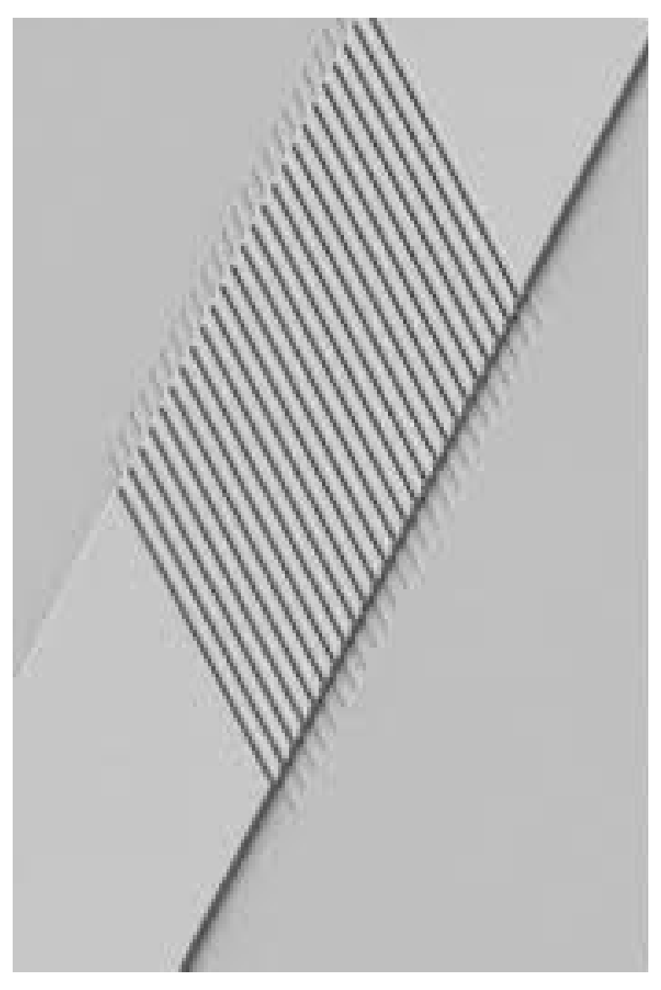

Figure 1.
SEM image of a photonic grating (3).

Computational Methods: We calculate the propagation of signal in two directions and compare the electric field profiles. The observed difference for the two cases allows for estimation of the mode mismatch between the coupled and scattered modes. Based on this comparison, we are able to calculate both the losses and coupled power. The losses originate from the mode mismatch between the signal scattered by grating and a fundamental fiber mode. We show that they can be minimized by implementing the proper profile into the grating.

The simulations were performed by FD and BM analysis of COMSOL RF module. We used two excitation schemes: one with the power entering through the waveguide and another with an incident beam irradiating the grating (the beam was supposed to arrive from an optical fiber). In the fiber excitation scheme, the incident light was launched from the white rectangle, as shown in Fig. 4. The electric field profile was set to be Gaussian along the rectangle front side inducing a Gaussian beam (Fig. 4.) through the grating center. The coupled and scattered powers were calculated through the power flow integration over the model internal boundaries. The undesirable reflections from the model boundaries were suppressed by self constructed absorbing layer with the linearly increasing imaginary part of refractive index. The mesh density was adjusted to be dense near the grating and sparse in distant areas. In the absorbing layer, numerical reflections were minimized by using a mapped mesh.

Matlab LiveLink™ was used to optimize the grating geometry in a semi-automated fashion. The code performed flipping of the geometry, stored electric field distributions, specified by unique ID string.

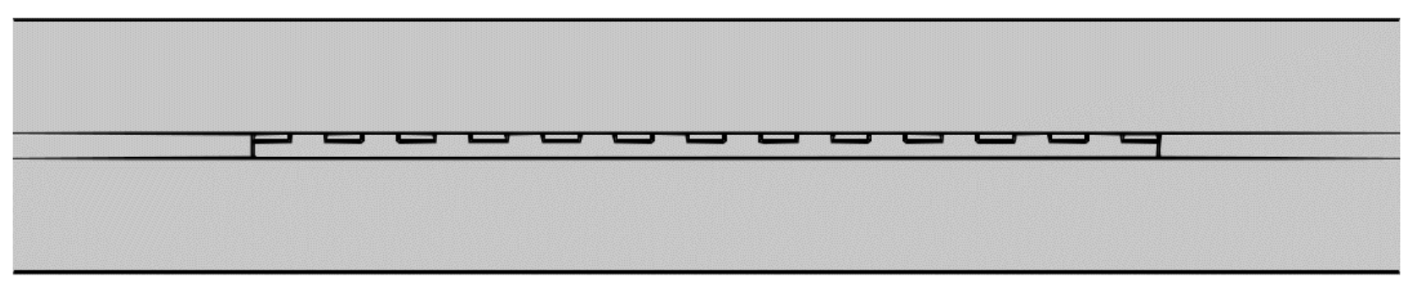

Figure 2a. Uniform grating.

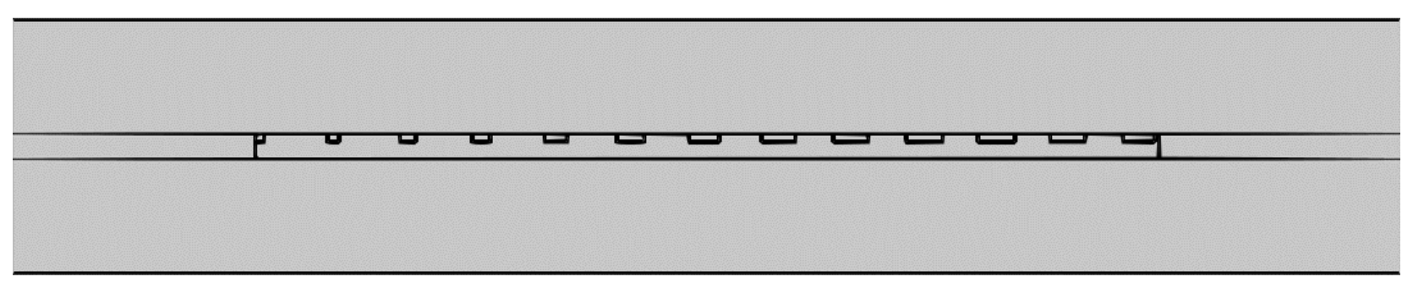

Figure 2b. Optimized geometry.

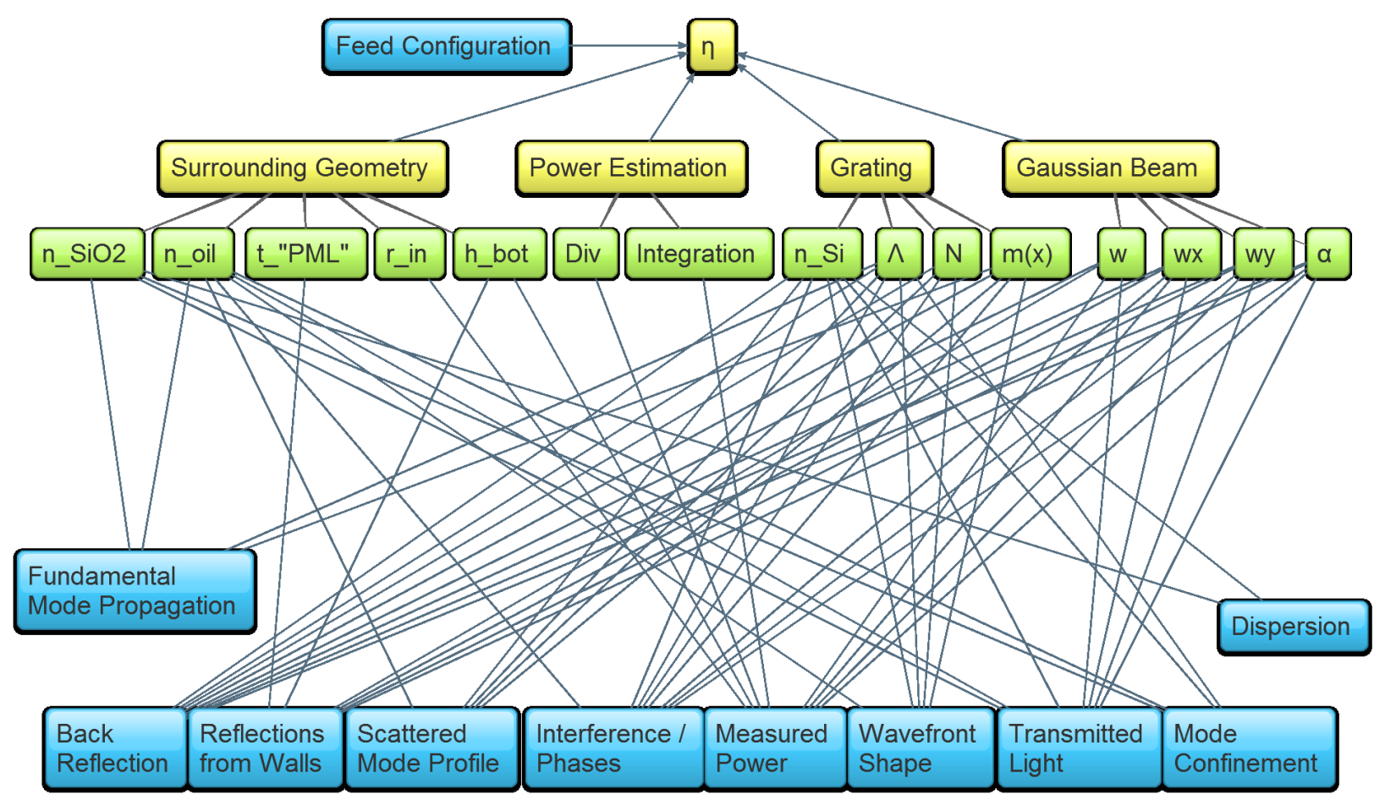

Figure 3. Significant parameters.

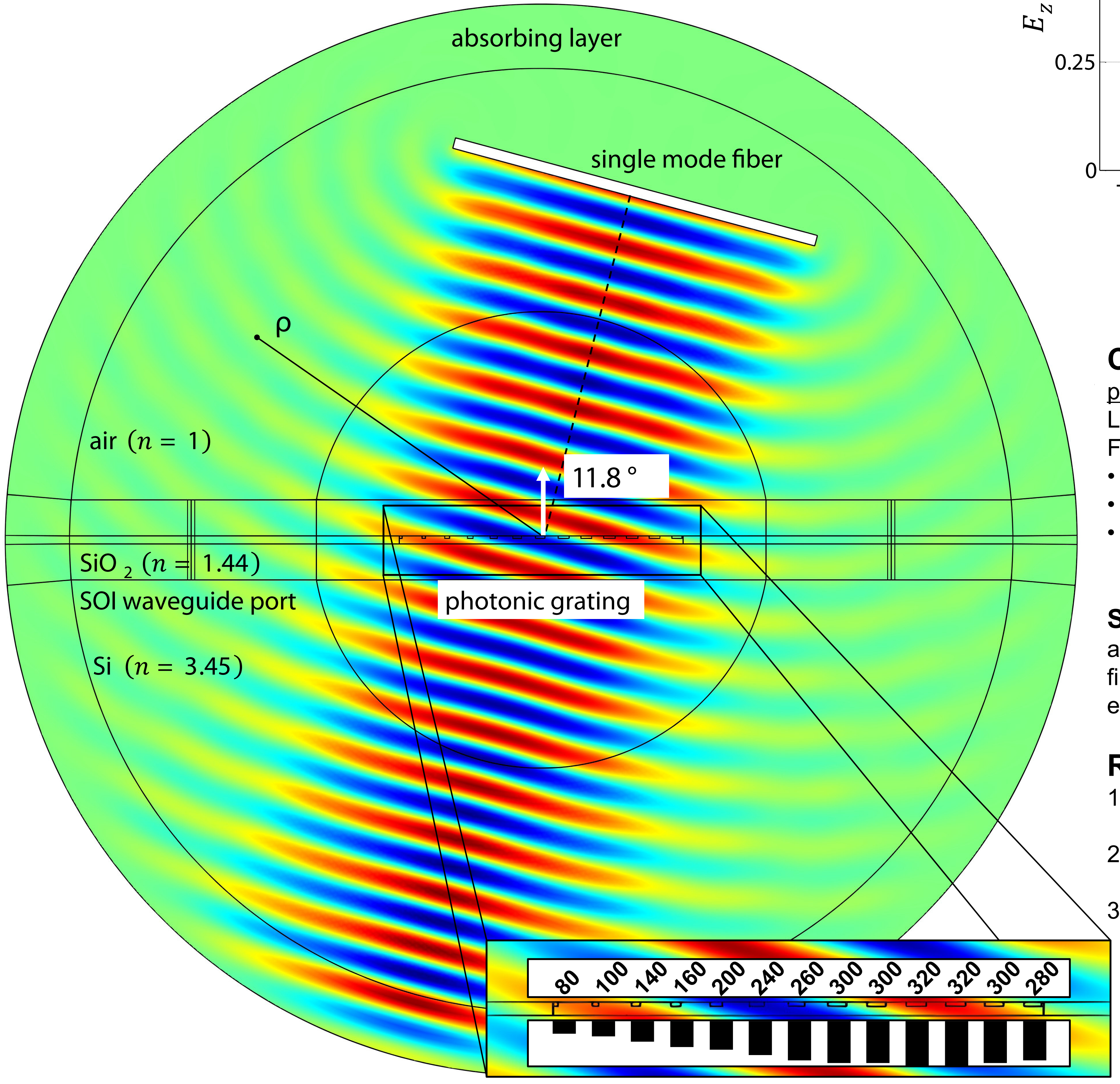

Figure 4. The model used in the simulations.

Governing equations:

Wave equation:

$$\nabla\times(\nabla\times\mathbf{E})-k_0^2n^2\mathbf{E}=\mathbf{0}$$

Absorbing layer index:

$$n(\rho)=n_r+i(\rho-\rho_0)/\Delta$$

Gaussian beam electric field:

$$|\mathbf{E}|=\hat{\mathbf{z}}\,E_0e^{-\rho^2/(2w_0{}^2)}\,\phi(z)e^{ik_0nz}$$

Phase matching condition:

$$\beta=k_0n\sin\alpha+m2\pi/\Lambda$$

Results: By tracing the electric field profiles for the two directions of excitation and the corresponding power values, we identified the optimized grating geometry (Fig. 2b). In this case, the coupled power reached 42% at 1.55um, while before the optimization it was only 35% (Fig. 5). Similarly, the scattered field profiles (Fig. 7) verified the improvement in coupling efficiency was due to the reduced mismatch between the signal provided by the grating and the fundamental fiber mode. The scattered powers were almost equal for both geometries, as shown in Fig. 5. This supports the idea the improvements are caused by the mode matching enhancement but not increased overall scattered power.

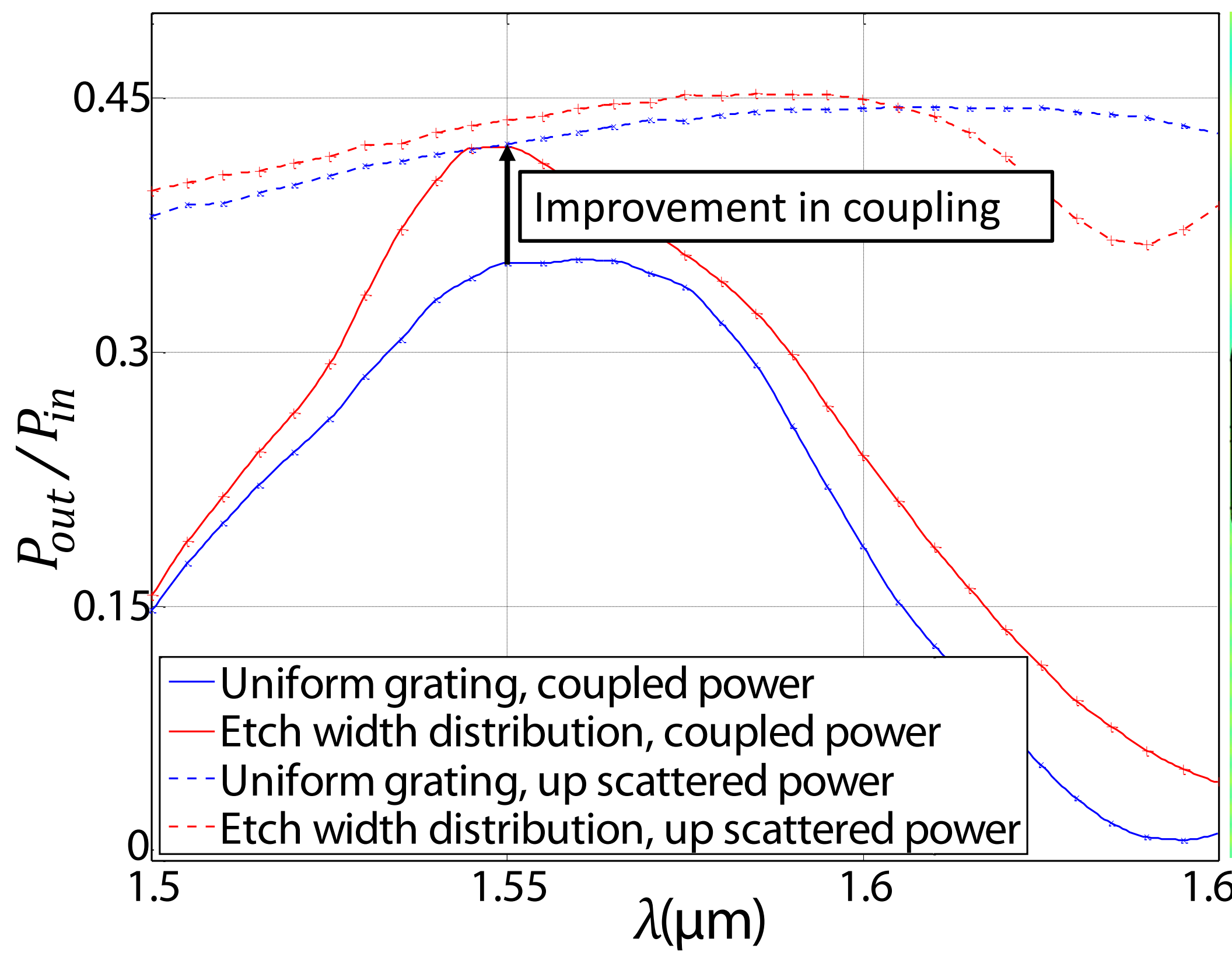

Figure 5. Frequency responses. (similar curves for the uniform case are calculated in (2)).

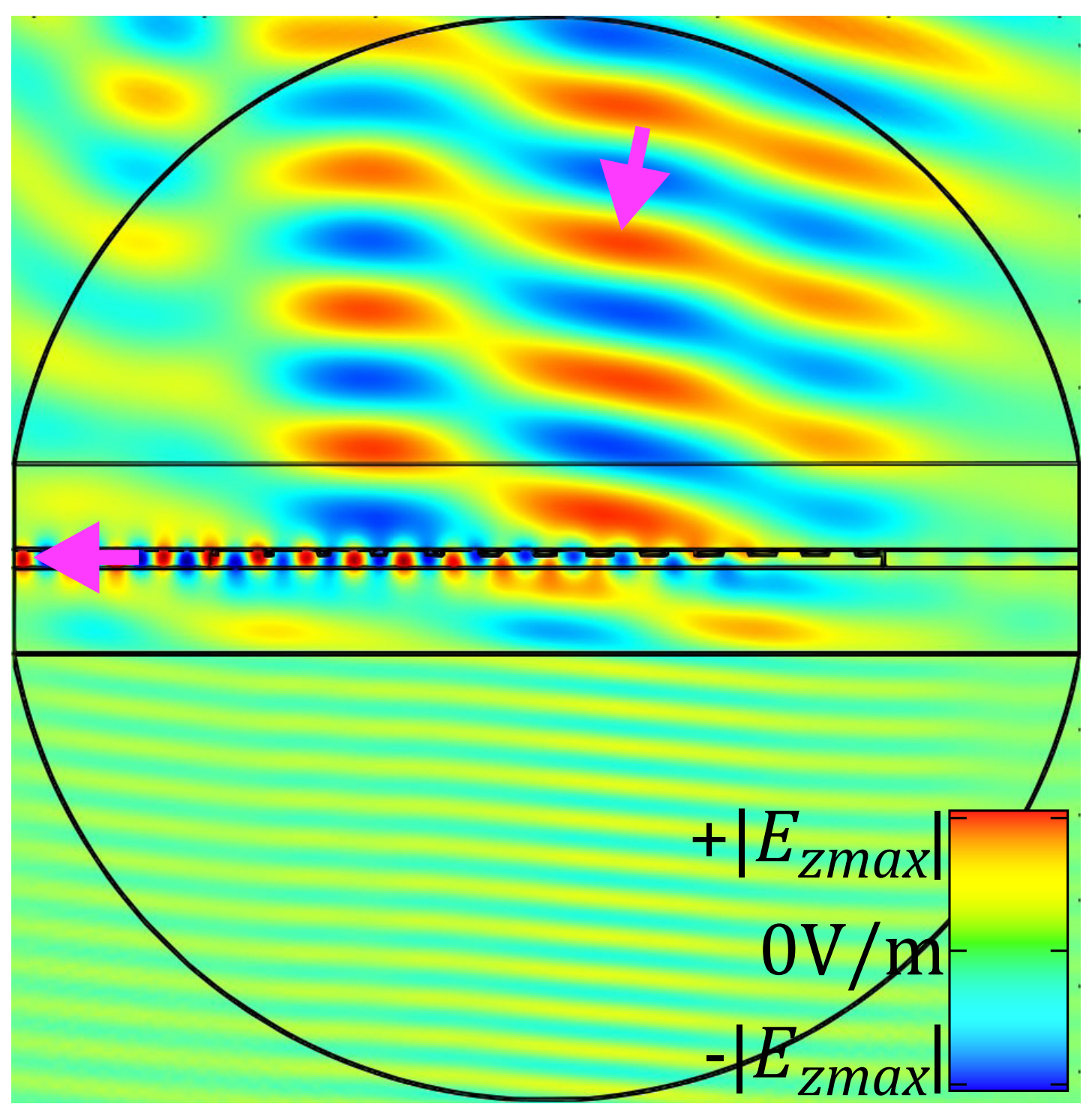

Figure 6. Coupling from the fiber (electric field z component).

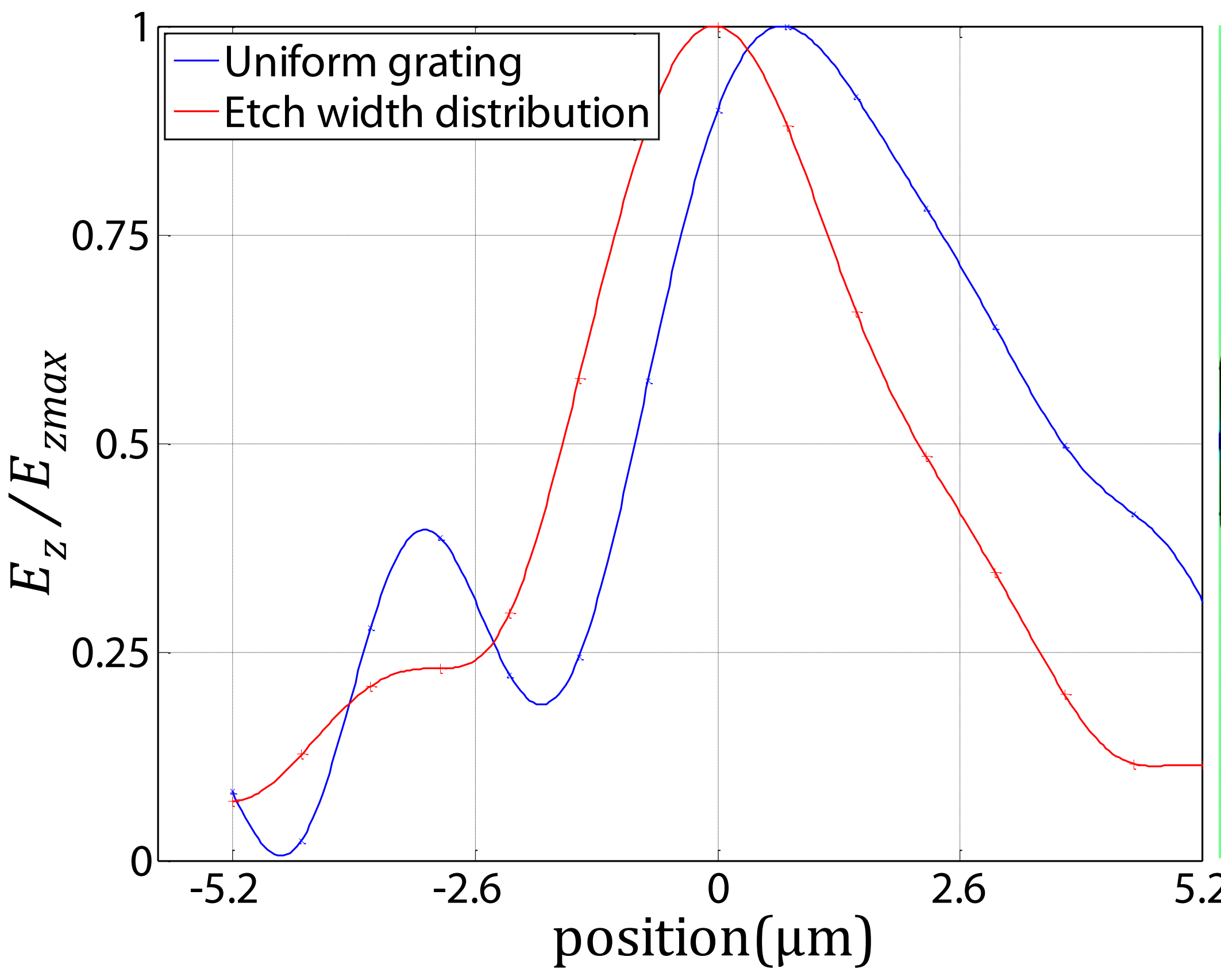

Figure 7. Scattered electric field profiles (normalized z component).

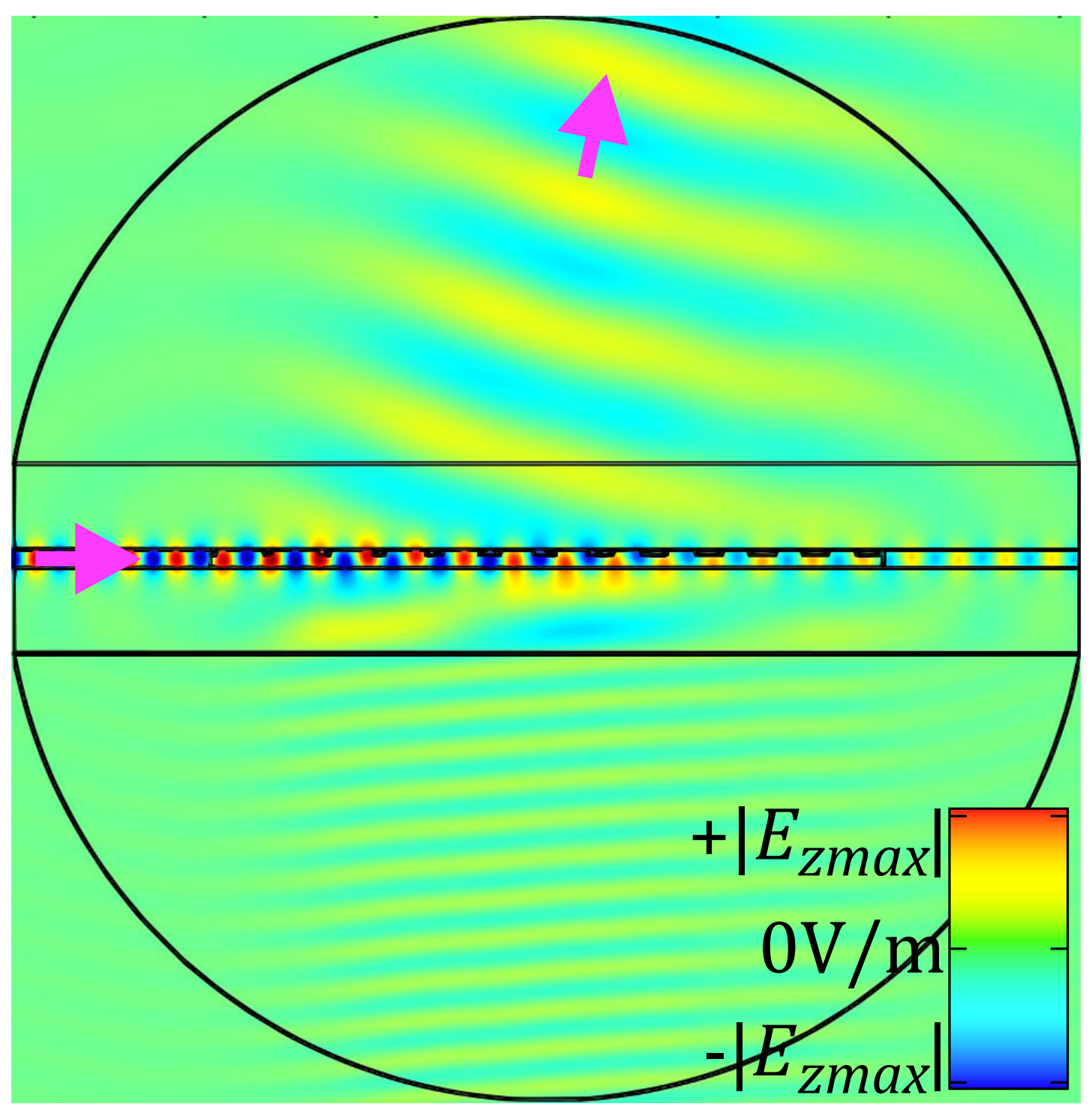

Figure 8. Coupling from the waveguide (electric field z-component).

Conclusions: The model represented in this study can be used to determine coupled power and coupling losses for various grating geometries. In addition, it is compatible with LiveLink™ based automatic calculation which allows for optimization of grating geometry. Following observations can be listed:

- The optimized geometry reaches higher coupling with smaller losses.
- The optimized geometry produces a focused beam of light in the fiber direction.
- The optimized geometry produces electric field distribution which resembles fundamental fiber mode.

Significance of the work: Improved coupling can benefit optical technology because it allows for better communication between a SOI microchip and a network composed of optical fibers. Development of optical technology has became important because traditional electronics is fundamentally speed limited by narrow bandwidths and energy consumption.

References:

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